CHAPTER 7. PLANT INSTRUMENTATION AND CONTROL

7.1 PROTECTIVE SYSTEMS

7.1.1 DESIGN BASIS

The reactor protection system receives, from plant instrumentation, signals which are indicative of an approach to an unsafe operating condition, actuates alarms, prevents control rod motion, initiates load cutback, and/or opens the reactor trip breakers, depending on the severity of the condition.

Every protection channel is at least duplicated (a one-out-of-two trip mode) and, in all cases for protection during power operation, at least triplicated (a two-out-of-three trip mode). The startup rate trip channel is one-out-of-two, the engineered safeguards trip channel is two-out-of-three and the nuclear overpower trip channel is two-out-of-four. The coincident trip philosophy (two of three or two of four) provides a safe and reliable system since a single failure will not defeat the function of the channel and will not cause a spurious plant trip. Channel independence is carried throughout the system extending from the sensor to the relay providing the two-out-of-three logic.

7.1.2 SYSTEM DESIGN

A simplified block diagram of the Reactor Protection System is shown in Figure 7-1. Individual reactor trip signals provided by the Reactor Protection System are:

a) Manual reactor trip: (1 out of 2 coincident circuits)
   Manual buttons are positioned for immediate use by plant operators when needed.

b) High startup rate: (1 out of 2 coincident circuits)
These circuits are tripped when the nuclear power exceeds a set point during operation in the intermediate range of the Nuclear Instrumentation System.

c) High nuclear flux: (2 out of 4 coincident circuits)
The trip set points for these circuits will be set at a low level during startup and set above full power during operation.

d) Safety injection initiation: (2 out of 3 low pressure coincident with 2 out of 3 low pressurizer level)
Actuation of the Safety Injection System will simultaneously initiate reactor trip signals.

e) Overpower-overtemperature: (2 out of 4 coincident circuits)
A reactor trip, derived from process control information, is provided to prevent reactor coolant conditions in the core which might lead to excessive fuel or cladding temperatures or to excessive bulk boiling. The set point for this reactor trip is continuously calculated from reactor coolant temperatures measured in the reactor coolant piping and measurements of pressurizer pressure.

f) Fixed high pressure: (2 out of 3 coincident circuits)
High pressurizer pressure will initiate a reactor trip. The purpose of these circuits is to protect the Reactor Coolant System against over-pressurization.

g) Loss of coolant flow: (2 out of 3 coincident circuits)
A signal of low coolant flow in any loop when operating above a preset power level will cause a reactor trip. Loss of reactor coolant pump power provides a similar initiation signal for this reactor trip.

h) Turbine-generator trip: (2 out of 3 coincident circuits)

Trip of the turbine-generator initiates a reactor trip to prevent excessive reactor coolant temperature and/or pressure.

i) Low steam generator water level: **(1 out of 2 feedwater-steam flow mismatch coincident with 1 out of 2 level)**

Redundant instrumentation is supplied to protect against loss of steam generator water inventory. These reactor trip signals are derived from measurements of feedwater flow, steam flow, and steam generator water level.

Reactor trip signals are interlocked with measurements of nuclear power and steam power to allow the necessary system operations and control rod movements during startup and to **bypass** the startup rate reactor trip when the reactor is in the power range of operation.

Wherever feasible, elements of reactor trip channels will be designed to trip the channel for the most probable failure of that channel.

All reactor trip signals will trip both reactor trip breakers through independent wiring. Also, a third independent reactor trip wiring circuit will be provided to trip the undervoltage coils on both breakers.

Automatic turbine load cutback is initiated by a signal of a dropped control rod cluster as indicated by either a rapid decrease in nuclear flux or by the rod bottom on-off controllers. This will prevent high power operation which might lead to unsafe core conditions because of the asymmetric nuclear flux distribution resulting from a dropped rod cluster. Automatic control rod withdrawal is also blocked for this condition.

Conditions which will block control rod withdrawal are listed below:

a) Rod drop (explained above)

b) High startup rate. This rod stop will block both manual and automatic control rod withdrawal. The set point for this rod stop will be less than that for the high startup rate reactor trip.

c) High nuclear flux. This rod stop will also block both manual and automatic rod withdrawal, and will be actuated at a lower value than the high nuclear flux reactor trip set point.

A lower insertion limit alarm circuit computes the lower limit to which the control group can be moved and maintain the required reactivity to follow load from no load to full load. Reactor coolant temperatures and control group position are used for this computation.

Alarms will also be used to alert the operator to deviation from normal operating conditions so that, where possible, he may take corrective action to avoid a reactor trip. Further, actuation of any rod stop or trip of any reactor trip channel will actuate an alarm.

7.2 CONTROL AND REGULATING SYSTEMS

7.2.1 DESIGN BASES

Overall reactivity control is achieved by the combination of chemical shim and control rod clusters. Long-term regulation of core reactivity is accomplished by adjusting the concentration of boric acid in the reactor coolant. Short-term reactivity control for power changes or reactor trip is provided by movement of control rod clusters. A simplified block diagram of the Reactor Control System is shown in Figure 7-2.

The primary function of the Reactor Control System is to provide automatic control of the rod clusters during power operation of the reactor. The system uses input signals including neutron flux, coolant temperature and pressure, and plant turbine load. The Chemical and Volume Control System serves as a secondary reactor control system by addition and removal of varying amounts of boric acid solution.

There is no provision for a continuous visual display of primary coolant boron concentration. When the reactor is critical, the best indication of reactivity status in the core is the position of the control group in relation to the power level and average coolant temperature. There is a direct, predictable, and reproducible relationship between rod position and power and it is this relationship which establishes the lower insertion limit calculated by the rod insertion limit monitor. There are two alarms to alert the operator to take corrective action in the event a control group approaches or reaches its lower limit.

Any unexpected change in the position of the control group under automatic control or a change in coolant temperature under manual control provides a direct and immediate indication of a change in the reactivity status of the reactor. In addition, periodic samples of coolant boron concentration are taken. The variation in concentration during core life provides a further check on the reactivity status of the reactor including core depletion.

The Reactor Control System will be designed to enable the reactor to follow load changes automatically when the plant output is above 15% of nominal power. Control rod positioning may be performed automatically when plant output is above this value, and manually at any time.

The system enables the nuclear plant to accept generation step load increases of 10% and ramp increases of 5% per minute within the load range of 15% to 100% without reactor trip subject to possible xenon limitations. Similar step and ramp load reductions are possible within the range of 100% to 15% of nominal power. Also, a condenser dump bypass will permit the plant to take a 40% loss in load without reactor or turbine trip.

7.2.2 SYSTEM DESIGN

7.2.2.1 Reactor Coolant Temperature Control

During steady-state operation, the primary function of the Reactor Coolant Temperature Control System maintains a programmed average reactor coolant temperature which rises in proportion to load. The control system also limits reactor plant system transients for prescribed load perturbations to within prescribed limits about this programmed temperature.

The measurements of the average temperatures are made by pairs of resistance thermometers in each of the reactor coolant loops. Elements in each cold leg in series with elements in the associated hot legs are used in electrical bridge circuits to produce outputs proportional to the average temperature.

The controller compares the average loop temperature with the programmed temperature, which is in turn set by a signal proportional to turbine-generator load.

The controller acts to direct a group of control rod clusters, fixed in number and location (the "control group"), to increase or decrease reactor power as required to maintain the desired average temperature. This group of rods is sequentially actuated with a proportional speed control (see Rod Drive Programmer). The sequential mode of operation provides fine temperature control for steady-state operation and long-term reactivity effects such as core burnup by limiting the stepwise reactivity insertion to that associated with a small number of rod clusters. For rapid reactivity requirements to accommodate relatively large changes in load, the control group is driven at a higher rate through the proportional speed control so that the rods in the control group move in rapid sequence.

A pressurizer pressure signal and a nuclear power signal are used in addition to the average temperature signal to improve the control response.

7.2.2.2 Steam Dump Control

A modulating steam dump control system is provided to remove sensible heat stored in the Reactor Coolant System following a plant trip. With the programmed average temperature, the full load average temperature is significantly greater than the saturation temperature corresponding to the steam generator safety valve set pressure. This, together with the fact that the thermal capacity in the Reactor Coolant System is greater than that of the steam system, requires a heat sink to prevent actuation of the steam generator safety valves following a plant trip. The total dump capacity to the condenser is 40 per cent of the steam flow at the steam pressure corresponding to plant operation at 100% power so that a 40% loss of load can be sustained without reactor or turbine trip.

7.2.2.3 Control of Shutdown Groups

The shutdown groups of control rods together with the control group are capable of shutting the reactor down. They are used in conjunction with the adjustment of chemical shim and the control group to maintain an adequate shutdown margin of at least one per cent for all normal operating conditions. These shutdown groups are manually controlled, except for automatic trip signals and are moved at a constant speed. They are fully withdrawn during power operation and are withdrawn first during startup. Criticality is always approached with the control group after withdrawal of the shutdown groups.

7.2.2.4 Interlocks

The control group used for automatic control is interlocked with measurements of turbine-generator load and reactor power to prevent automatic control rod withdrawal below 15% of nominal power. The manual and automatic controls are further interlocked with measurements of nuclear flux, and rod drop indication to prevent approach to an overpower condition.

7.2.2.5 Rod Drive Programmer

The control group is driven by a sequencing, variable speed rod drive programmer. In the control group of RCC assemblies, control subgroups (each containing a small number of RCC assemblies) are moved sequentially in a cycle such that all subgroups are maintained within one step of each other.

The sequence of motion is reversible, that is, a withdrawal sequence is the reverse of the insertion sequence. The sequencing speed is proportional to the control signal from the reactor control system. This provides control group speed control proportional to the demand signal from the control system.

A rod drive mechanism control center is provided to receive sequenced signals from the programmer and to actuate contactors in series with the coils of the rod drive mechanisms. Two reactor trip breakers are placed in series with the supply for these coils.

7.2.2.6 Control Rod Cluster Position Indication

Two methods of indicating control position are provided. The first method of indicating positions of control rod shutdown groups and control group rod subgroups is by counting the number of steps that the rods in a group have been moved by the magnetic jacks. This is accomplished by pulse transmitting contacts associated with the cycling mechanisms of the programmer and magnetic jack contactors feeding a digital readout device. For each step by a group of rod clusters, the digital readout receives an impulse and adds to or subtracts from the previously indicated position.

A second method of rod position detection is provided by position transmitters for the individual rods which are electrical coil stacks placed above the stepping mechanisms of the control rod magnetic jacks external to the pressure housing. When the associated control rod is at the bottom of the core, the magnetic coupling between a primary and secondary is small with an associated small voltage induced in the secondary coils. As the control rod is raised by the magnetic jacks, the relatively high permeability of the lift rod causes an increase in magnetic coupling. Thus an analog signal proportional to rod position is derived. Rod bottom lights are provided to indicate the approximate fully inserted rod position. In addition, a multipoint recorder is provided to record position of the rods in selected groups as determined by the operator for particular operating conditions.

7.2.2.7 Rod Drive Power Supply

The DC power for the entire complement of rod drive mechanisms is provided by a system composed of two AC motor generator sets and static rectifier assemblies. The sets will consist of squirrel cage induction motors driving synchronous alternators.

The total capacity of the system including the overload capability of each motor generator set is such that a single set out of service will not cause limitations in rod motion during normal plant operation. In order to minimize reactor trip as a result of a unit malfunction, the power system will normally be operated with both units in service.

Flywheels on the motor generator sets and high speed regulators on each unit will enable the rods to ride through a complete loss of AC power for one second during electrical transients.

7.3 NUCLEAR INSTRUMENTATION SYSTEM

7.3.1 DESIGN BASIS

The function of the Nuclear Instrumentation System, Figure 7-3, is to monitor the reactor power from source range through the intermediate ranges and up to 120 per cent of full power. This is accomplished by means of thermal neutron flux detectors located in instrument wells in the primary shield area adjacent to the reactor vessel. The system provides indication, control and alarm signals for reactor operation and protection. The overlap of the ranges of detection is indicated on Figure 7-4.

7.3.2 SYSTEM DESIGN

7.3.2.1 Detectors

The system employs six detector assemblies located in instrument wells around the reactor. Two of these detector assemblies contain proportional counters used in the source range channels, and compensated ion chambers, used in the intermediate range channels. They are located in vertical instrument wells adjacent to two opposite "flat" portions of the core at an elevation equal to the axial center of the core.

The other four detector assemblies are long ionization chambers approximately equal to the core height, in which the inner electrodes are divided into two equal sections to supply in effect a total of eight separate uncompensated ionization chambers approximately one-half the core height. The four long ionization chamber assemblies are located in vertical instrument wells adjacent to the four "corners" of the core.

7.3.2.2 Source Range

There are two source range channels utilizing proportional counters as neutron detectors. Neutron flux, as measured in the primary shield area, produces current pulses in the detectors. These pulses are applied to transistor amplifiers and discriminators located in the control room.

These channels indicate the source range neutron flux, and provide high flux level trip signals to the Reactor Control and Protection System. An audible count rate signal in both the reactor containment and control room is provided for use during refueling and the initial phases of startup.

7.3.2.3 Intermediate Range

There are two intermediate range channels, which use two compensated ionization chambers. Direct current from the ion chambers is transmitted through cables to transistor current amplifiers in the control room.

These channels indicate the intermediate range neutron flux and provide high flux level rod stop and alarm signals and high flux level reactor trip signals. They also automatically disconnect the high voltage from the source range detectors when the neutron flux is in the intermediate range.

7.3.2.4 Power Range

There are three sets of power range measurements, each using four individual currents as follows:

a) Four currents directly from the lower sections of the long ionization chambers.
b) Four currents directly from the upper sections.
c) Four total currents of (a) and (b), equivalent to the average of each section.

For each of the four currents in (a) and (b), the current measurement is indicated by a microammeter. The total current equivalent to the average is then applied to an amplifier and bistable trip circuit. The amplifiers are equipped with gain and bias controls for adjustment to the actual current corresponding to the equivalent per cent of reactor thermal power.

Each of the four amplifiers also provides amplified currents to the main control board for indication and for use in the Reactor Control System. Each set of bistable trip outputs is operated in 2-out-of-4 coincidence to initiate a reactor trip. Bistable trip outputs are provided at different power set points to provide protection during startup and at full power operation.

A bistable trip circuit is provided as an indication of an approach to overpower condition and initiates a rod stop.

A dropped rod condition initiates a rodstop signal and turbine load cutback. A dropped rod condition is indicated by a rapid decrease in any one power range channel.

The four amplifier signals for (c) are supplied to circuits which compares the current in all channels. Alarms are provided to annunciate deviations which might be indicative of quadrant flux asymmetry.

7.3.2.5 Auxiliary Equipment

A conventional micro-microammeter may be connected to any one of the power range detectors for use in physics tests.

Four indicators are mounted on the main control board to provide delta flux indication for each long ion chamber.

A large two-pen strip chart recorder is mounted on the main control board for use by the plant operators. It includes a range switch for changing the span and suppression during intermediate range operation or complete coverage of the source and the intermediate ranges. Four two-pen strip chart recorders are mounted on the main control board and record the detector current from each long ion chamber section.

7.3.2.6 Overpower Trip

The maximum calculated overpower of 112% is made possible by use of long ionization chambers and improved electronic devices. The long ion chambers, which extend over almost the entire core length, give a more accurate indication of flux changes than a combination of detectors at the top and bottom of the core. The design allowance for drift and reproducibility error in the electronic devices is a design goal and will be established by manufacturer's tests.

Preliminary design parameters for the system to give a maximum overpower of 112% are given in Table 7-1.

TABLE 7-1

Maximum Overpower Level

Trip Setpoint	106.5%
Calorimetric Error	2.0%
Errors in Ion Chamber Output Due to RCC Position for Design Transient	1.5
Errors Due to Drift and Set Point Reproducibility	2.0%
Maximum Overpower	112.0%

7.4 NON-NUCLEAR PROCESS INSTRUMENTATION

Much of the process instrumentation provided in the plant has been described in the Reactor Control and Protection System and Nuclear Instrumentation System. The more important instrumentation used to monitor and control the plant has been covered in detail in the above systems. The remaining portion of the process instrumentation is generally shown on the process flow diagrams which have been included to illustrate the operations and processes of the various auxiliary systems and the turbine-generator plant.

The amounts and types of the various instruments and controllers shown are intended to be typical examples of those which will be included in the various systems when final design details have been completed.

7.5 IN-CORE INSTRUMENTATION

7.5.1 DESIGN BASIS

The in-core instrumentation is designed to yield information on the neutron flux distribution and fuel assembly outlet temperatures at selected core locations. Using the information obtained from the in-core instrumentation system, it will be possible to confirm the reactor core design parameters and calculated hot channel factors.

7.5.2 SYSTEM DESIGN

The in-core instrumentation system consists of chromel-alumel thermocouples positioned to measure fuel assembly coolant outlet temperature at preselected locations and flux thimbles which run the length of selected fuel assemblies to measure the neutron flux distribution within the reactor core. The exact number and locations will be set following final selection of the control rod pattern.

The experimental data obtained from the in-core temperature and flux distribution instrumentation system in conjunction with previously determined analytical information can be used to determine the fission power distribution in the core at any time throughout core life. This method is more accurate than using calculational techniques alone. Once the fission power distribution has been established, the maximum power output is primarily determined by thermal and hydraulic conditions existing within the core. A combination of the fission power distribution and the thermal and hydraulic limitations determines the maximum core capability.

The in-core instrumentation provides information which may be used to calculate the coolant enthalpy distribution, the fuel burnup distribution, and an estimate of the coolant flow distribution.

7.5.2.1 Thermocouples

The chromel-alumel thermocouples are threaded into guide tubes that penetrate the reactor vessel head through seal assemblies, and terminate at the exit flow end of the fuel assemblies. The thermocouples are enclosed in stainless steel sheaths within the above tubes. Thermocouple readings are recorded on multipoint recorders located in the control room. The support of the thermocouple guide tubes in the upper core support assembly is described in Section 3.2.3.

7.5.2.2 Movable Miniature Neutron Flux Detectors

These detectors will be remotely positioned in the core and will provide remote readout for flux mapping. Retractable thimbles into which the miniature detectors will be driven are pushed into the reactor core through conduits which extend from the bottom of the reactor vessel down through the concrete shield area and then up to a thimble seal line. (See Figures 3-38, 7-5 and 7-6).

The thimbles will be closed at the leading ends, will normally be dry inside, and will serve as the pressure barrier between the reactor water pressure and the atmosphere. Mechanical seals between the retractable thimbles and the conduits will be provided at the seal line.

During normal operation, the retractable thimbles will be stationary. They will be retracted approximately 14 ft. for maintenance or during refueling to avoid interference within the core, at which time a space of approximately 14 ft. above the seal line must be cleared for the retraction operation.

The drive system for the insertion of the miniature detectors will consist of the drive assemblies, path-group selector assemblies and the rotary selector assemblies. The drive system will push hollow helical-wrap drive cables into the core with the miniature detectors attached to the leading ends of the cables and small diameter sheathed electrical coaxial cables threaded through the hollow centers back to the trailing ends of the drive cables.

Each drive assembly mainly consists of: a two-speed synchronous gear motor that provides sufficient power to push a drive cable and detector through any path; a drive box with a drive wheel that couples with the helical-wrap drive cable and is driven by the gear motor (the top half of the drive wheel cover shall be readily removable in order to insert the drive cable by pushing the leading end with the detector attached into the flux thimble, and pushing the trailing end with an electrical seal attached back to the storage reel); and a storage device consisting of a takeup reel that accommodates the total drive cable length.

One path-group selector is provided for each drive unit to route the detector into a common group for calibration.

Each rotary transfer assembly mainly consists of: a rotary transfer device that routes a detector into any one of up to ten selectable paths; and up to ten isolation valves, manually operated to close the thimble runs after removal of the detector. Each of these valves, when open, shall allow free passage of the detector and drive cable and when closed shall prevent steam leakage from the core in case of a thimble rupture.

7.6 OPERATING CONTROL

7.6.1 CENTRAL CONTROL ROOM

All control, instrumentation displays and alarms required for the safe operation and shutdown of the plant will be readily available to the operator in a single, central control room. Instrumentation displays such as indicators and recorders will be provided in the control room to keep the operator informed of process flows, pressures and temperatures as well as other operating conditions throughout the plant. Visual-audible annunciators and printout equipment in the control room will alert the operator in the event of abnormal plant conditions which may lead to fuel damage, component damage or to other potentially unsafe conditions.

The Reactor Turbine Generator Control Console will contain all of the controls and indications necessary for the safe operation of both the nuclear steam system and the conventional plant equipment. The control stations on the console will be packaged in a modular concept and will be grouped according to function to facilitate control and minimize the possibility of operating error.

7.6.2 LOCAL CONTROL PANELS

Local control panels will be provided for certain systems and components which do not require the attention of a full-time operator or which are used occasionally. Examples of such systems are the Waste Disposal System and the Turbine Generator Hydrogen Coolant System. In these cases, appropriate alarms will be provided in the control room to indicate equipment malfunction or abnormal conditions.

7.6.3 LOSS OF LOAD

The unit is designed to sustain any step load decrease, less than or equal to 40 per cent of rated load, without a trip of the turbine or reactor. The reactor-turbine control system together with the steam dump system will respond automatically to reduce reactor power to equal the required load.

A step load decrease of greater than 40 per cent will cause tripping of the turbine and reactor, if necessary, to prevent excessive reactor coolant temperature and/or pressure.

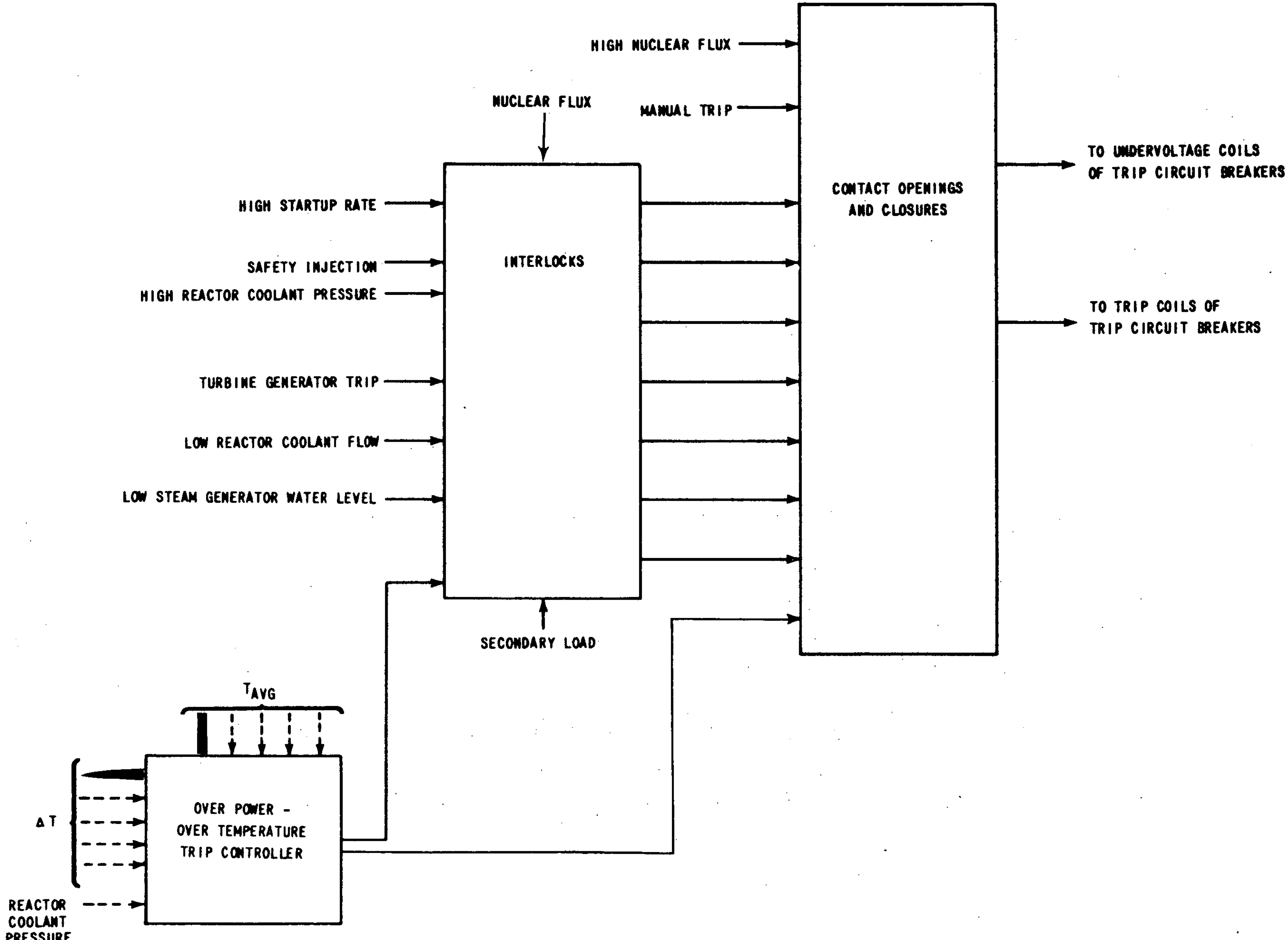
7.7 CONTAINMENT INSTRUMENTATION

Containment pressure, temperature and sump level instrumentation will be provided to monitor containment conditions from the control room during all phases of plant operation.

The number and location of the pressure transmitters will be so selected and located to provide maximum reliability for the indication and alarming of containment pressure during normal and accident conditions.

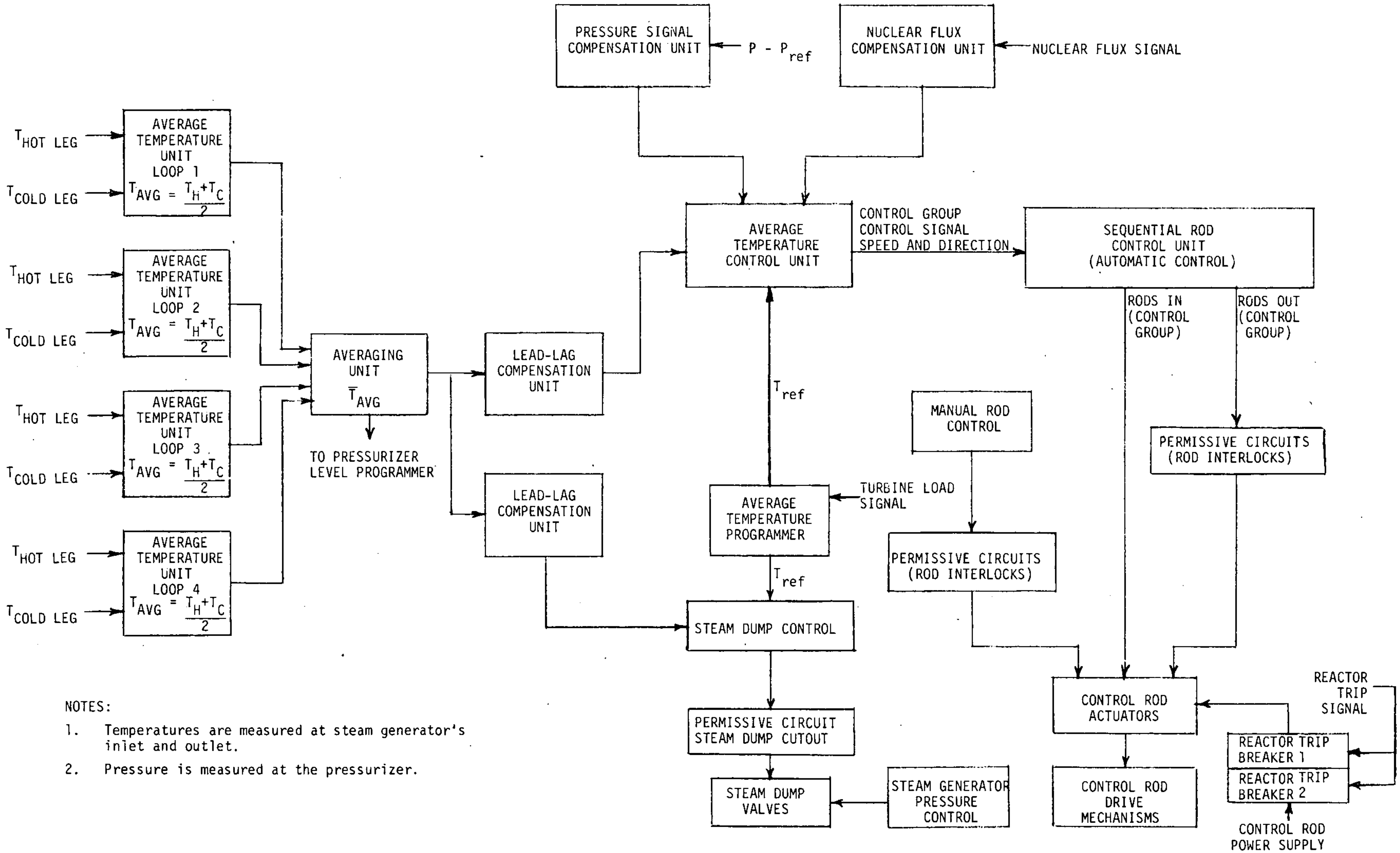
Air temperature and containment cooler air discharge temperature detectors will be provided for monitoring and evaluating containment air cooling system equipment.

Redundant containment sump level indicators will be installed to monitor and alarm sump level during normal and emergency plant conditions.



REACTOR PROTECTION SYSTEM

REACTOR PROTECTION SYSTEM
FIG. 7-1

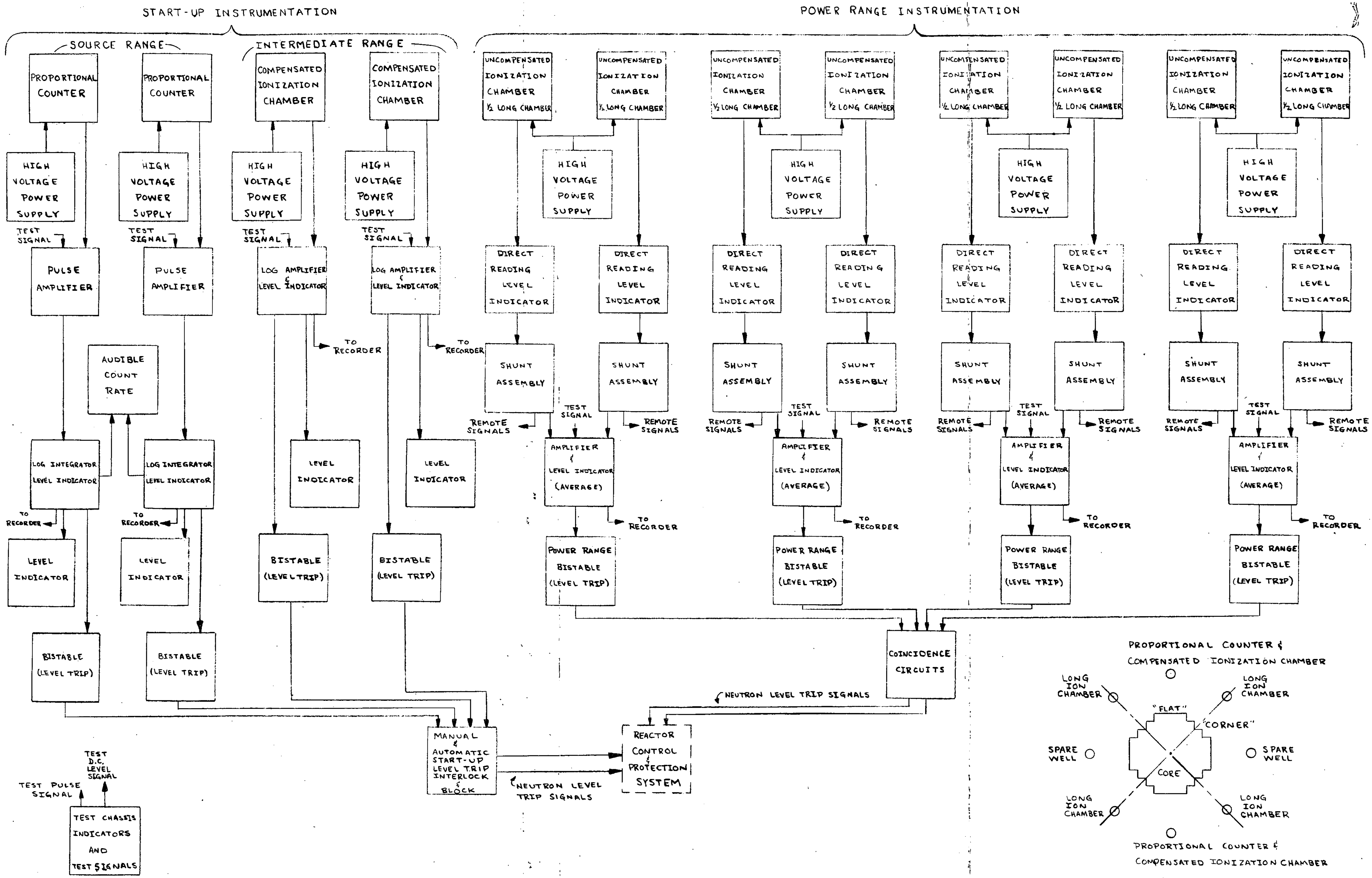


NOTES:

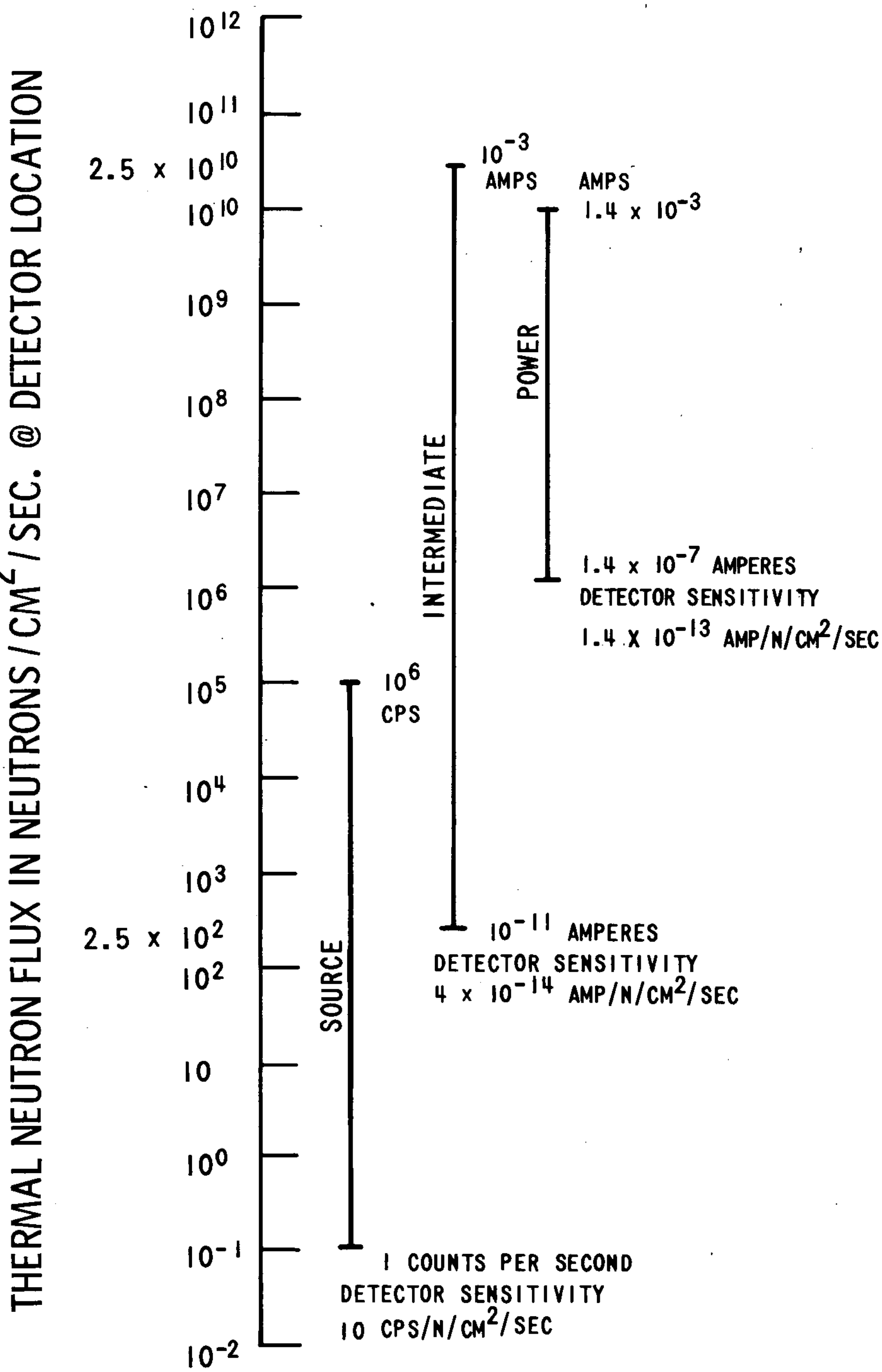
1. Temperatures are measured at steam generator's inlet and outlet.
2. Pressure is measured at the pressurizer.

SIMPLIFIED BLOCK DIAGRAM OF REACTOR CONTROL SYSTEMS

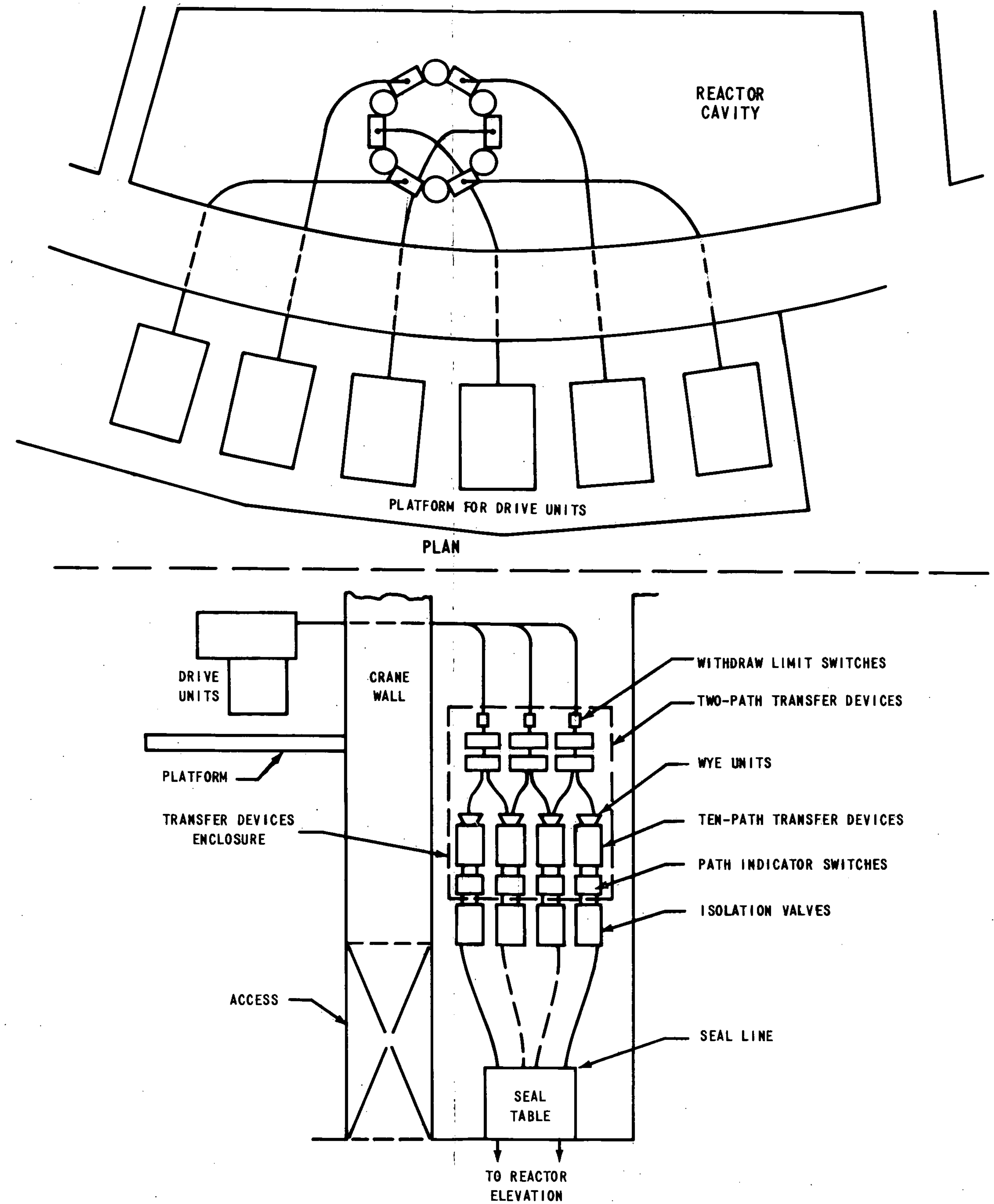
FIG. 7-2



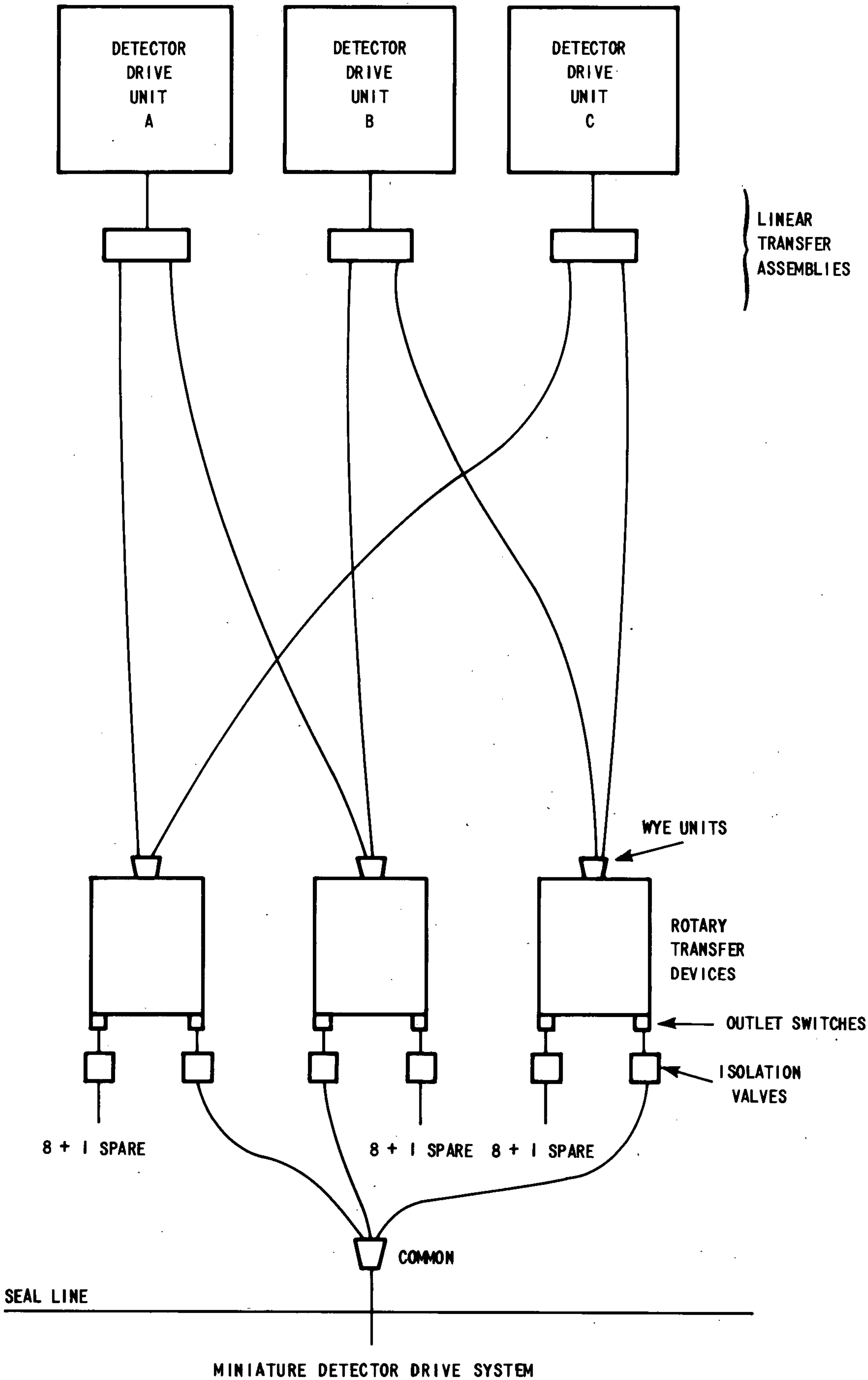
NUCLEAR INSTRUMENTATION SYSTEM
FIG. 7-3



NEUTRON DETECTORS AND RANGE OF OPERATION
FIG. 7-4



ARRANGEMENT OF IN-CORE FLUX DETECTOR
FIG. 7-5



SCHEMATIC OF IN-CORE FLUX DETECTOR DRIVE SYSTEM
FIG. 7-6

SECTION 8

PSAR Section	Page	Remarks
8.1	8-1	Item 1 of Supplement 1 to the PSAR gives the general design criteria for the design basis for the electrical systems. The following GDC are specifically referenced: GDC 2 page 3 GDC 24 page 31 GDC 39 page 50
8.2	8-1	A typographical error occured in the second paragraph of Section 8.2. Figure 3-1 referred to should be Figure 8-1.
8.3.3	8-5	The battery chargers referred to in the third line of Section 8.3.3 should read "the battery" as referred in Supplement 7, Question 6 (m). General references to additional material on the electrical systems follow: a) Quality assurance and quality control for the electrical systems appear in Supplement 1, Item 5 and Supplement 5, Items 4 and 10. b) Information on the emergency power supply at the site is found in Supplement 1, Item 17 (F - 1.0) and Supplement 7, Question 2 and 6. c) Information on bus faults is found in Supplement 1, Item 17 (F-2.0). d) Additional information on the power sources is found in Supplement 1, Items 17 (F - 3.0) and 17 (F - 4.0). e) Information on environmental tests of electrical equipment in the containment is given in Supplement 1, Item 17 (F - 5.0) and Supplement 7, Question 6. f) Other specific areas of the electrical system are covered in Supplement 7, Question 6.